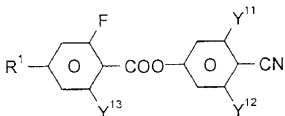


# Electro-optical liquid-crystal display and liquid-crystal medium

The invention relates to an electro-optical liquid-crystal display having a realignment layer, for realigning the liquid crystals, whose field has a component parallel to the liquid-crystal layer which is crucial for the realignment, containing a liquid-crystalline medium of positive dielectric anisotropy, where the medium comprises at least one mesogenic compound of the formula I



wherein

R¹ is H, alkyl or alkoxy having 1 to 7 carbon atoms or alkenyl, alkenyloxy or alkoxyalkyl having 2 to 7 carbon atoms, and

Y¹¹, Y¹² and Y¹³ are each, independently of one another, H or F.

In conventional liquid-crystal displays (TN, STN, OMI AMD-TN), the electric fields for the realignment are generated essentially perpendicular to the liquid-crystal layer.

International Patent Application WO 91/10936 discloses a liquid-crystal display in which the electric signals are generated in such a way that the electric fields have a significant component parallel to the liquid-crystal layer (IPS, in-plane switching). The principles of operation of a display of this type are described, for example, by R.A. Soref in Journal of Applied Physics, Vol. 45, No. 12, pp. 5466-5468 (1974).

For example, EP 0 588 568 discloses various possibilities for designing the electrodes and for addressing a display of this type. DE 198 24 137 likewise describes  
5 various embodiments of IPS displays of this type.

Liquid-crystalline materials for use in IPS displays of this type are described, for example, in DE 198 48 181.

- 10 IPS displays containing the known liquid-crystalline media are characterized by inadequately long response times and often by excessively high operating voltages. There is thus a need for IPS displays which do not have these disadvantages, or only do so to a reduced extent.
- 15 Liquid-crystalline materials required for this purpose are in particular those which, in addition to an adequate phase range, a low crystallization tendency at low temperatures, a low birefringence and an adequate electrical resistance, in particular have low threshold
- 20 voltages ( $V_{10}$ ) and low rotational viscosities ( $\gamma_1$ ) which are crucial for the response times.

Surprisingly, this object has been achieved by using liquid-crystalline materials which comprise at least  
25 one compound of the formula I.

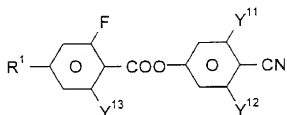
Upon further study of the specification and appended claims, further objects and advantages of this invention will become apparent to those skilled in the  
30 art.

The IPS mixtures according to the invention are notable for their relatively high clearing points, their low rotational viscosities and their low thresholds.

35

The invention thus relates to an electro-optical liquid-crystal display having a realignment layer, for realigning the liquid crystals, whose field has a significant component parallel to the liquid-crystal

layer, containing a liquid-crystalline medium of positive dielectric anisotropy, where the medium comprises at least one compound of the formula I



5

in which

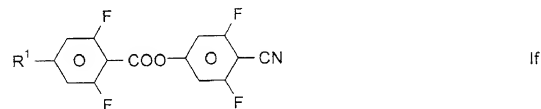
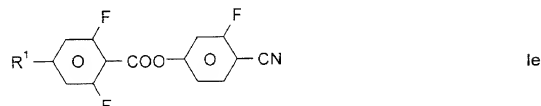
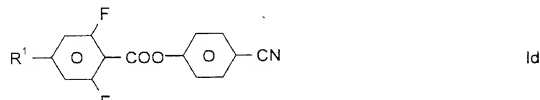
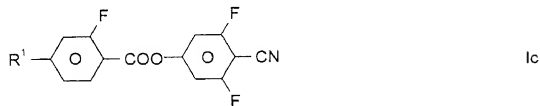
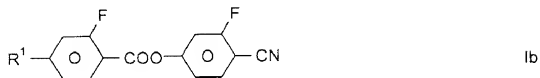
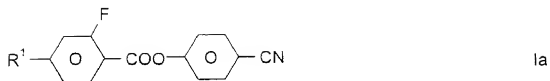
10  $R^1$  is alkyl or alkoxy having 1 to 7 carbon atoms, preferably n-alkyl or n-alkoxy, particularly preferably having 1 to 5 carbon atoms, or alkenyl, alkenyloxy or alkoxyalkyl having 2 to 7 carbon atoms, preferably 1E-alkenyl, 1E-alkenyloxy or  
15 straight-chain alkoxylalkyl, particularly preferably having 2 to 5 carbon atoms and

$Y^{11}$ ,  $Y^{12}$  and  $Y^{13}$  are each, independently of one another, H or F.

20

Particular preference is given to liquid-crystal displays containing a liquid-crystal medium which comprises at least one compound of the formula I in which at least one of the radicals  $Y^{11}$  to  $Y^{13}$  is F. Very  
25 particular preference is given to such liquid-crystal displays containing a liquid-crystal medium which comprises at least one compound of the formula I in which at least one of the radicals  $Y^{11}$  and  $Y^{12}$  is F.

30 The liquid-crystal displays preferably contain liquid-crystal media which comprise at least one compound selected from the group consisting of the compounds of the formulae Ia to If



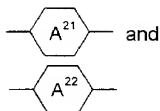
Particular preference is given to compounds selected from the group consisting of the compounds of the subformulae Ic, Ie and If, very particularly preferably of the subformulae Ic and If.

Preference is furthermore given to liquid-crystal displays containing a liquid-crystalline medium which comprises one or more compound(s) of the formula II

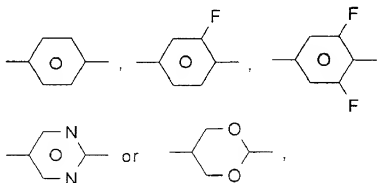


in which

$R^2$  is alkyl or alkoxy having 1 to 7 carbon atoms or alkenyl, alkenyloxy or alkoxyalkyl having 2 to 7 carbon atoms,



are each, independently of one another,

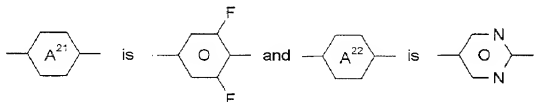


$X^2$  is F, Cl, CN or NCS, and

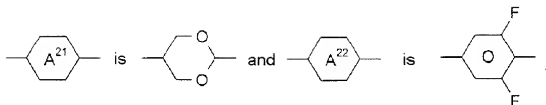
$Z^2$  is  $CH_2CH_2$ , COO,  $CF_2O$  or a single bond,

with the proviso that compounds of the formula I are excluded.

Particular preference is given to compounds of the formula II in which



Preference is furthermore given to compounds of the formula II in which



Preference is furthermore given to compounds of the formula II in which  $X^2$  is CN.

- 5 Preference is furthermore given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compound(s) of the formula III

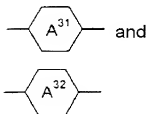


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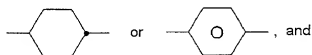
in which

$R^{31}$  and  $R^{32}$  are each, independently of one another,  
 alkyl or alkoxy having 1 to 7 carbon atoms  
 15 or alkenyl, alkenyloxy or alkoxyalkyl  
 having 2 to 7 carbon atoms,

20



are each, independently of one another,



$Z^{31}$  is  $CH=CH$ ,  $COO$ ,  $CH_2CH_2$  or a single bond.

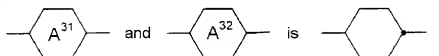
- 25 Particular preference is given to compounds of the formula III in which at least one of the radicals  $R^{31}$

and  $R^{32}$  is alkenyl having 2 to 7 carbon atoms, preferably 2 or 3 carbon atoms.

Preference is furthermore given to compounds of the formula III in which  $Z^{31}$  is  $CH=CH$  or a single bond.

Preference is furthermore given to compounds of the formula III in which

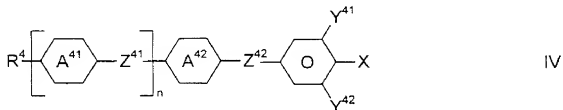
at least one of



particularly preferably both are



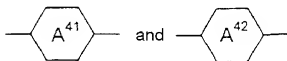
Preference is furthermore given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compounds of the formula IV



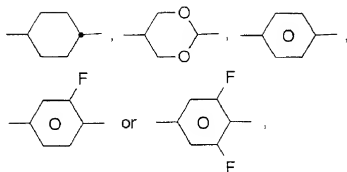
in which

is

$R^4$  is alkyl or alkoxy having 1 to 7 carbon atoms or alkenyl, alkenyloxy or alkoxyalkyl having 2 to 7 carbon atoms,



are each, independently of one another,



$Z^{41}$  and  $Z^{42}$  are each, independently of one another,  $CF_2O$ ,  $COO$ ,  $CH_2CH_2$ ,  $CF=CF$ ,  $CH=CH$ ,  $CF=CH$ ,  $CH=CF$  or a single bond,

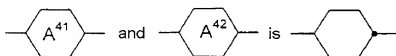
$n$  is 0 or 1,

$X$  is  $OCF_3$ ,  $OCF_2H$  or  $F$ ,

and

$Y^{41}$  and  $Y^{42}$  are each, independently of one another,  $H$  or  $F$ .

Particular preference is given to compounds of the formula IV in which at least one of



Preference is furthermore given to compounds of the formula IV in which  $Z^{41}$  and  $Z^{42}$  are each, independently of one another,  $CH_2CH_2$  or a single bond.

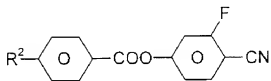
Preference is furthermore given to compounds of the formula IV in which  $X$  is  $OCF_3$  and  $Y^{41}$  and  $Y^{42}$  are  $H$ , and to compounds of the formula IV in which  $X$  is  $F$  and  $Y^{41}$  and  $Y^{42}$  are  $F$ .



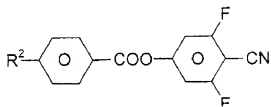
Particular preference is given to media which comprise at least one compound of the formula I and at least one compound of the formula II.

- 5 Particular preference is given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compound(s) of the formula II selected from the group consisting of the subformulae IIa to IIe.

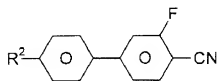
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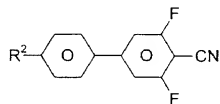
IIa



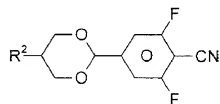
IIb



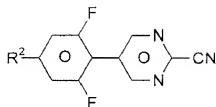
IIc



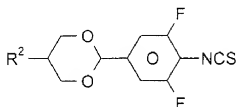
IIId



IIe



II f



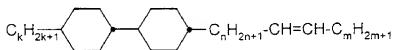
II e

in which  $R^2$  is as defined above under formula II.

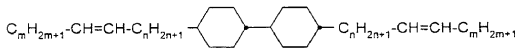
- 5 The liquid-crystal display particularly preferably contains a liquid-crystalline medium comprising one or more compound(s) selected from the group consisting of compounds of the subformulae IIa, IIc, IId, IIE and II f, in particular IIE and II f.

- 10 Preference is furthermore given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compound(s) of the formula III selected from the group consisting of the subformulae

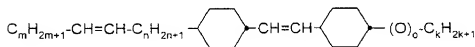
- 15 IIIa to IIIc.



III a



III b



III c

where

20

k is 1, 2, 3, 4 or 5,

m and n are each, independently of one another, 0, 1, 2 or 3, and  $m + n \leq 5$ , and

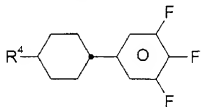
o is 0 or 1.

5

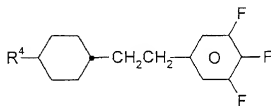
Preference is furthermore given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compound(s) of the formula IV selected from the group consisting of the subformulae

10

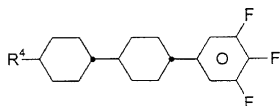
IVa to IVc.



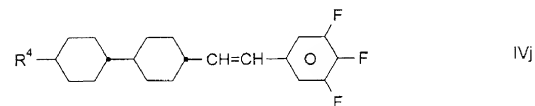
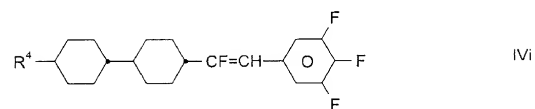
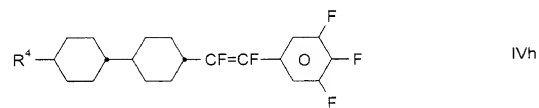
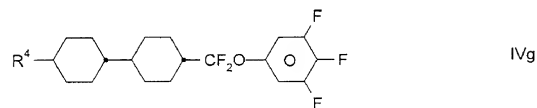
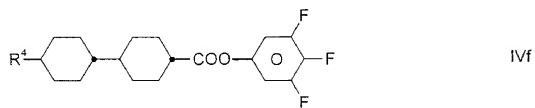
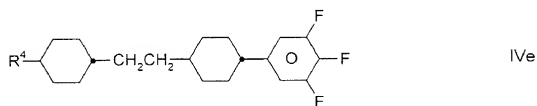
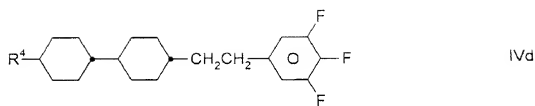
IVa

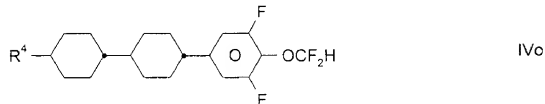
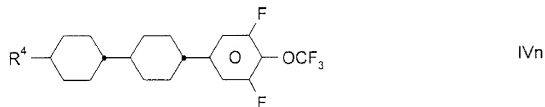
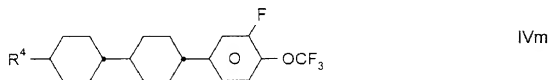
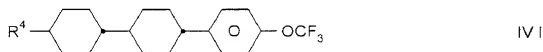
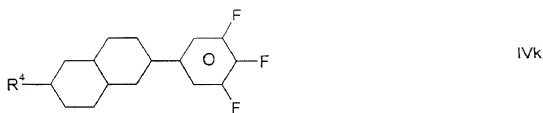


IVb



IVc

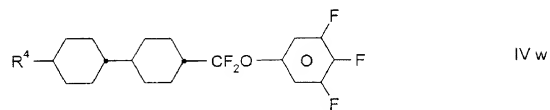
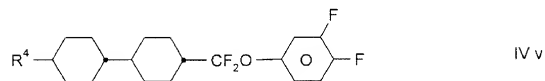
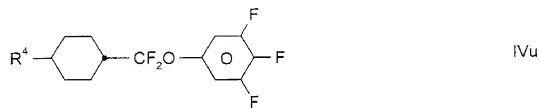
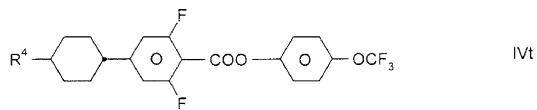
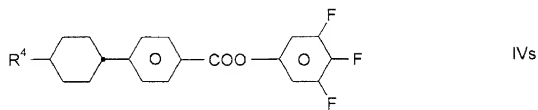
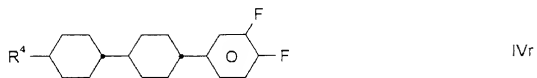
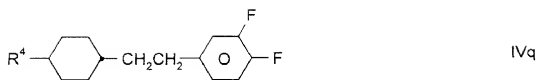


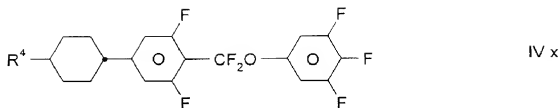


in which R<sup>4</sup> is as defined above under formula IV.

- 5 Preference is furthermore given to liquid-crystal displays in which the liquid-crystalline medium comprises one or more compound(s) of the formula IV selected from the group consisting of the subformulae IVp to IVr and/or the group consisting of the subformulae IVs to IVx.







in which R<sup>4</sup> is as defined above under formula IV.

- 5 In another preferred embodiment, the liquid-crystal display cells contain liquid-crystalline media comprising one or more compounds of the subformula Ic, the concentration of each of these compounds being in the range from 0.1 to 20%, preferably from 1 to 16%,  
 10 particularly preferably from 2 to 12%, very particularly preferably from 3 to 10%.

In a preferred embodiment of the invention, the liquid-crystal display cells contain liquid-crystalline media comprising one or more compounds of the formula If, the concentration of each of these compounds being from 0.1 to 18%, preferably from 1 to 14%, particularly preferably from 2 to 10%.

- 20 The following liquid-crystal displays are preferred embodiments:

- the medium additionally comprises one or more compounds selected from the group of the formulae Va and Vb

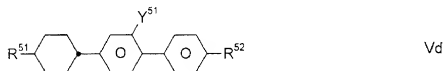
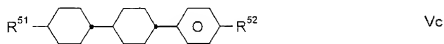


- 30 in which R<sup>51</sup> and R<sup>52</sup> are each, independently of one another, alkyl or alkoxy having 1 to 7 carbon atoms or alkenyl, alkenyloxy or alkoxyalkyl having

2 to 7 carbon atoms,  $R^{51}$  preferably being alkyl having 1 to 5 carbon atoms,  $R^{52}$  preferably being alkyl or alkoxy, in paritucular alkoxy, having 1 to 3 carbon atoms,

and/or

one or more compounds selected from the group of the formulae Vc and Vd



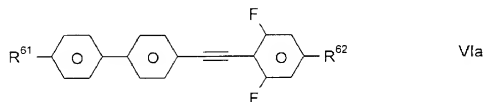
in which

$R^{51}$  and  $R^{52}$  independently of one another, are as defined above,  $R^{51}$  preferably being n-alkyl having 3 to 5 carbon atoms, and  $R^{52}$  preferably being n-alkyl,

and

$Y^{51}$  is H or F;

the medium additionally comprises one or more compounds of the formula VIa



in which



$R^{61}$  and  $R^{62}$  are each, independently of one another, alkyl or alkoxy having 1 to 7 carbon atoms, preferably alkyl having 1 to 5 carbon atoms.

5

Preference is given to displays containing liquid-crystal mixtures comprising

10 - one or more compounds of the formula Va

in which, preferably, at least one of the groups  $R^{51}$  and  $R^{52}$  is alkenyl, preferably 1E-alkenyl, particularly preferably vinyl or 1E-propenyl,

15 - one or more compounds of the formula Vb

in which, preferably,

20  $R^{51}$  is n-alkyl having 3 to 5 carbon atoms, particularly preferably having 3 to 5 carbon atoms,

and

25  $R^{52}$  is alkoxy having 1 to 3 carbon atoms, particularly preferably having 1 carbon atom,

30 - one or more compounds of the formula Vc

30

in which

$R^{51}$  is n-alkyl having 1 to 5 carbon atoms, preferably having 1 to 3 carbon atoms,

35

and

$R^{52}$  is 1E-alkenyl having 2 to 5 carbon atoms, preferably having 2 to 3 carbon atoms,

- one or more compounds of the formula Vd

in which

5

$R^{51}$  is n-alkyl having 1 to 5 carbon atoms,  
preferably having 1 to 3 carbon atoms,

10  $R^{52}$  is n-alkyl having 1 to 5 carbon atoms,  
preferably having 2 to 4 carbon atoms,

and

$y^{51}$  is preferably H.

15

Preference is furthermore given to a liquid-crystal display according to the invention in which the pixels are addressed by means of an active matrix.

20 The invention furthermore relates to a liquid-crystalline medium of positive dielectric anisotropy which comprises at least one compound of the formula I, and at least one compound selected from the group consisting of the compounds of the formulae IIa to IIi and IIIa to IIIc, and at least one compound selected from the group consisting of the compounds of the formulae IVa and IVo, in particular which comprises

30 - from 2 to 30, preferably from 3 to 20, % by weight of at least one compound of the formula I,

35 - from 5 to 25, preferably from 5 to 18, % by weight of at least one compound of the formula II, preferably selected from the group consisting of the compounds of the formulae IIa to IIi,

- from 5 to 40, preferably from 10 to 30, % by weight of at least one compound of the formula III, preferably selected from the group consisting of the compounds of the subformulae IIIa to IIIc,  
5
  - from 5 to 50, preferably from 20 to 40, % by weight of at least one compound of the formula IV, preferably selected from the group consisting of the compounds of the subformulae IVa to IVc.  
10
- 15 The liquid-crystalline media used in accordance with the invention generally have a birefringence ( $\Delta n$ ) of  $< 0.12$ , preferably  $\Delta n$  is in the range from 0.05 to 0.11, in particular in the range from 0.07 to 0.10, with clearing points of 70 to 90°C.
- 20 The flow viscosity (at 20°C) of the mixtures used in accordance with the invention is generally less than  $30 \text{ mm}^2 \cdot \text{s}^{-1}$ , in particular from 15 to  $25 \text{ mm}^2 \cdot \text{s}^{-1}$ . The resistivity of the materials according to the invention
- 25 at 20°C is generally from  $5 \times 10^{10}$  to  $5 \times 10^{13} \Omega \cdot \text{cm}$ , particularly preferably from  $5 \times 10^{11}$  to  $5 \times 10^{12} \Omega \cdot \text{cm}$ . The rotational viscosity of the mixtures according to the invention at 20°C is generally less than  $130 \text{ mPa} \cdot \text{s}$ , in particular from 70
- 30 to  $110 \text{ mPa} \cdot \text{s}$ .

The Fredericksz threshold voltages of the mixtures according to the present invention are low, preferably 1.7 V or less, more preferably 1.5 V or less, most

35 preferably 1.3 V or less, and in particular 1.1 V or less.

Media used in accordance with the invention having clearing points of from 70 to 80°C have rotational

viscosities of 120 mPa · s or less, preferably of 110 mPa · s or less, particularly preferably from 70 mPa · s to 100 mPa · s, very particularly preferably from 40 mPa · s to 90 mPa · s.

- 5 The clearing point of the media used in accordance with the invention is above 60°C, preferably above 70°C and particularly preferably 80°C or more. In particular, the clearing point is in the range from 60°C to 80°C. The storage stability in test cells, determined as
- 10 described below, is 1000 hours or more at -30°C, preferably 500 hours or more at -40°C, very particularly preferably 1000 hours or more at -40°C.

- The media used in accordance with the invention consist
- 15 of from 5 to 30 compounds, preferably from 6 to 20 compounds, particularly preferably from 7 to 16 compounds.

- It has been found that even a relatively small
- 20 proportion of compounds of the formula I mixed with conventional liquid-crystal materials, but in particular with one or more compounds selected from the group consisting of the compounds of the formulae IIa to IIf and/or from the group consisting of the
- 25 compounds of the formulae IIIa to IIIf and IVa to IVo, results in a significant reduction in the threshold voltage, in favourable values for the rotational viscosity  $\gamma_1$  and in fast response times, in particular broad nematic phases having low smectic-nematic
- 30 transition temperatures being observed. The compounds of the formulae I to IV are colourless, stable and readily miscible with one another and with other liquid-crystal materials.

- 35 The term "alkyl" encompasses straight-chain and branched alkyl groups having 1-7 carbon atoms, in particular the straight-chain groups methyl, ethyl, propyl, butyl, pentyl, hexyl and heptyl. Groups having

2-5 carbon atoms are preferred, unless explicitly stated otherwise.

The term "alkenyl" encompasses straight-chain and  
5 branched alkenyl groups having 2-7 carbon atoms, in particular the straight-chain groups. Particularly preferred alkenyl groups are C<sub>2</sub>-C<sub>7</sub>-1E-alkenyl, C<sub>4</sub>-C<sub>7</sub>-3E-alkenyl, C<sub>5</sub>-C<sub>7</sub>-4-alkenyl, C<sub>6</sub>-C<sub>7</sub>-5-alkenyl and C<sub>7</sub>-6-alkenyl, in particular C<sub>2</sub>-C<sub>7</sub>-1E-alkenyl,  
10 C<sub>4</sub>-C<sub>7</sub>-3E-alkenyl and C<sub>5</sub>-C<sub>7</sub>-4-alkenyl. Examples of very particularly preferred alkenyl groups are vinyl, 1E-propenyl, 1E-butenyl, 1E-pentenyl, 1E-hexenyl, 1E-heptenyl, 3E-butenyl, 3E-pentenyl, 3E-hexenyl, 3E-heptenyl, 4-pentenyl, 4Z-hexenyl, 4E-hexenyl,  
15 4Z-heptenyl, 5-hexenyl, 6-heptenyl and the like. Groups having up to 5 carbon atoms are preferred, unless explicitly stated otherwise.

The term "fluoroalkyl" preferably encompasses straight-chain groups containing terminal fluorine, i.e.  
20 fluoromethyl, 2-fluoroethyl, 3-fluoropropyl, 4-fluorobutyl, 5-fluoropentyl, 6-fluorohexyl and 7-fluoroheptyl. However, other positions of fluorine are not excluded.

25 The term "alkoxyalkyl" preferably encompasses straight-chain radicals of the formula C<sub>n</sub>H<sub>2n+1</sub>-O-(CH<sub>2</sub>)<sub>m</sub>, in which n and m are each, independently of one another, from 1 to 6. m is preferably 1 and n is preferably from 1 to 4.

30 A suitable choice of the meanings of R<sup>1</sup> to R<sup>52</sup> allows the response times, the threshold voltage, the steepness of the transmission characteristic lines etc. to be modified as desired. For example, 1E-alkenyl  
35 radicals, 3E-alkenyl radicals, 2E-alkenyloxy radicals and the like generally result in shorter response times, improved nematic tendencies and a higher ratio of the elastic constants k<sub>33</sub> (bend) and k<sub>11</sub> (splay) compared with alkyl or alkoxy radicals. 4-Alkenyl

radicals, 3-alkenyl radicals and the like generally result in lower threshold voltages and smaller values of  $k_{33}/k_{11}$  compared with alkyl and alkoxy radicals.

- 5 The optimum weight ratio of the compounds of the formulae I-IV depends substantially on the desired properties, on the choice of the components of the formulae I, II, III and/or IV, and on the choice of any other components which may be present. Suitable weight  
10 ratios within the range given above can easily be determined from case to case.

- The total amount of compounds of the formulae I to IV in the mixtures used according to the invention is not  
15 critical. The mixtures preferably comprise 50-90% by weight of compounds of the formulae I to IV. The mixtures may also comprise one or more further components in order to optimize various properties. However, the observed effect, particularly on the  
20 threshold voltage, is generally greater the higher the total concentration of compounds of the formulae I to IV, in particular of the formula I.

- In a particularly preferred embodiment, the media  
25 according to the invention comprise compounds of the formula IV in which X is  $\text{OCF}_3$ . A favourable synergistic effect with the compounds of the formulae I and II results in particularly advantageous properties.

- 30 In addition to one or more compounds of the formula I, the liquid-crystalline media according to the invention preferably comprise from 2 to 40, in particular from 4 to 30, compounds as further constituents. These media very particularly preferably comprise from 7 to 15  
35 compounds in addition to one or more compounds of the formula I. These further constituents are preferably selected from nematic or nematogenic (monotropic or isotropic) substances, in particular substances from the classes of the azoxybenzenes, benzylideneanilines,

biphenyls, terphenyls, phenyl or cyclohexyl benzoates, phenyl or cyclohexyl esters of cyclohexanecarboxylic acid, phenyl or cyclohexyl esters of cyclohexylbenzoic acid, phenyl or cyclohexyl esters of cyclohexyl-  
 5 cyclohexanecarboxylic acid, cyclohexylphenyl esters of benzoic acid, of cyclohexanecarboxylic acid and of cyclohexylcyclohexanecarboxylic acid, phenylcyclohexanes, cyclohexylbiphenyls, phenylcyclohexylcyclohexanes, cyclohexylcyclohexanes, cyclohexylcyclohexylcyclo-  
 10 hexenes, 1,4-bis-cyclohexylbenzenes, 4,4'-bis-cyclohexylbiphenyls, phenyl- or cyclohexylpyrimidines, phenyl- or cyclohexylpyridines, phenyl- or cyclohexyldioxanes, phenyl- or cyclohexyl-1,3-dithianes, 1,2-diphenylethanes, 1,2-dicyclohexylethanes, 1-phenyl-2-  
 15 cyclohexylethanes, 1-cyclohexyl-2-(4-phenylcyclohexyl)ethanes, 1-cyclohexyl-2-biphenylethanes, 1-phenyl-2-cyclohexylphenylethanes, optionally halogenated stilbenes, benzyl phenyl ethers, tolans and substituted cinnamic acids. The 1,4-phenylene groups in these compounds  
 20 may also be fluorinated.

The most important compounds suitable as further constituents of media used according to the invention can be characterized by the formulae 1, 2, 3, 4 and 5:

25	R' -L-E-R"	1
	R' -L-COO-E-R"	2
	R' -L-OOC-E-R"	3
	R' -L-CH <sub>2</sub> CH <sub>2</sub> -E-R"	4
30	R' -L-C≡C-E-R"	5

In the formulae 1, 2, 3, 4 and 5, L and E, which may be identical or different, are in each case, independently of one another, a bivalent radical from the group  
 35 consisting of -Phe-, -Cyc-, -Phe-Phe-, -Phe-Cyc-, -Cyc-Cyc-, -Pyr-, -Dio-, -G-Phe- and -G-Cyc- and their mirror images, where Phe is unsubstituted or fluorine-substituted 1,4-phenylene, Cyc is trans-1,4-cyclohexylene or 1,4-cyclohexylene, Pyr is pyrimidine-

2,5-diyl or pyridine-2,5-diyl, Dio is 1,3-dioxane-2,5-diyl and G is 2-(trans-1,4-cyclohexyl)ethyl, pyrimidine-2,5-diyl, pyridine-2,5-diyl or 1,3-dioxane-2,5-diyl.

- 5 One of the radicals L and E is preferably Cyc, Phe or Pyr. E is preferably Cyc, Phe or Phe-Cyc. The media according to the invention preferably comprise one or more components selected from the compounds of the formulae 1, 2, 3, 4 and 5 in which L and E are selected
- 10 from the group consisting of Cyc, Phe and Pyr and simultaneously one or more components selected from the compounds of the formulae 1, 2, 3, 4 and 5 in which one of the radicals L and E is selected from the group consisting of Cyc, Phe and Pyr and the other radical is
- 15 selected from the group consisting of -Phe-Phe-, -Phe-Cyc-, -Cyc-Cyc-, -G-Phe- and -G-Cyc-, and optionally one or more components selected from the compounds of the formulae 1, 2, 3, 4 and 5 in which the radicals L and E are selected from the group consisting
- 20 of -Phe-Cyc-, -Cyc-Cyc-, -G-Phe- and -G-Cyc-.

- In a smaller subgroup of the compounds of the formulae 1, 2, 3, 4 and 5, R' and R" are each, independently of one another, alkyl, alkenyl, alkoxy, alkoxyalkyl,
- 25 alkenyloxy or alkanoyloxy having up to 8 carbon atoms. This smaller subgroup is called Group A below, and the compounds are denoted by the subformulae 1a, 2a, 3a, 4a and 5a. In most of these compounds, R' and R" are different from one another, one of these radicals
- 30 usually being alkyl, alkenyl, alkoxy or alkoxyalkyl.

- In another smaller subgroup of the compounds of the formulae 1, 2, 3, 4 and 5 which is called Group B, R" is -F, -Cl, -NCS or  $-(O)_iCH_3-(k+1)F_kCl_1$ , where i is 0 or 1, and
- 35 k+1 is 1, 2 or 3; the compounds in which R" has this meaning are denoted by the subformulae 1b, 2b, 3b, 4b and 5b. Particular preference is given to those compounds of the subformulae 1b, 2b, 3b, 4b and 5b in which R" is -F, -Cl, -NCS, -CF<sub>3</sub>, -OCHF<sub>2</sub> or -OCF<sub>3</sub>.



In the compounds of the subformulae 1b, 2b, 3b, 4b and 5b, R' is as defined for the compounds of the subformulae 1a-5a and is preferably alkyl, alkenyl, alkoxy or alkoxyalkyl.

In a further smaller subgroup of the compounds of the formulae 1, 2, 3, 4 and 5, R" is -CN; this subgroup is called Group C below, and the compounds of this subgroup are correspondingly described by subformulae 1c, 2c, 3c, 4c and 5c. In the compounds of the subformulae 1c, 2c, 3c, 4c and 5c, R' is as defined for the compounds of the subformulae 1a-5a and is preferably alkyl, alkoxy or alkenyl.

In addition to the preferred compounds from Groups A, B and C, other compounds of the formulae 1, 2, 3, 4 and 5 having other variants of the proposed substituents are also customary. All these substances can be obtained by methods which are known from the literature or analogously thereto.

In addition to the compounds of the formulae I to IV, the media used according to the invention preferably comprise one or more compounds selected from Group A and/or Group B and/or Group C. The proportions by weight of the compounds from these groups in the media according to the invention are preferably

Group A: from 0 to 90%, preferably from 20 to 90%, in particular from 30 to 90%  
Group B: from 0 to 80%, preferably from 10 to 80%, in particular from 10 to 65%  
Group C: from 0 to 80%, preferably from 5 to 80%, in particular from 5 to 50%,

the sum of the proportions by weight of the Group A and/or B and/or C compounds present in the particular

media used according to the invention preferably being from 5% to 90% and in particular from 10% to 90%.

5 The media used according to the invention preferably comprise from 1 to 40%, particularly preferably from 5 to 30%, of compounds of the formula I. The media preferably comprise two or more compounds of the formula I.

10 The construction of the IPS displays according to the invention corresponds to the usual design of displays of this type, as described, for example, in WO 91/10936 or EP 0 588 568. The term "conventional design" is broadly drawn here and also covers all variations and  
15 modifications of the IPS display, in particular, for example, also matrix display elements based on poly-Si TFT or MIM.

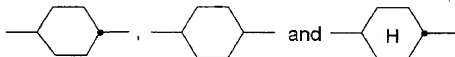
20 However, an essential difference between the displays according to the invention and the conventional displays lies in the choice of the liquid-crystal parameters of the liquid-crystal layer.

The liquid-crystal mixtures which are used in accordance  
25 with the invention are prepared in a manner which is customary per se. In general, the desired amount of the components used in the smaller amount is dissolved in the components making up the principal constituent, advantageously at elevated temperature. It is also  
30 possible to prepare the mixtures in other conventional manners, for example by using pre-mixtures, for example mixtures of homologues, or using so-called "multi-bottle" systems which, for example, consist of four  
35 basic mixtures which differ significantly from one another in only one physical property in each case.

The dielectrics may also comprise further additives known to the person skilled in the art and described in the literature. For example, 0-15%, preferably 0-10%, of

pleochroic dyes and/or chiral dopants can be added. The individual compounds added are employed in concentrations of from 0.01 to 6%, preferably from 0.1 to 3%. However, the concentrations of the other constituents of the liquid-crystal mixtures, i.e. the liquid-crystalline or mesogenic compounds, are given without taking into account the concentration of these additives.

10 Above and below,



are trans-1,4-cyclohexylene.

The physical properties of the liquid-crystal mixtures are determined as described in "Physical Properties of Liquid Crystals", Ed. W. Becker, Merck KGaA, status Nov. 1997, unless explicitly stated otherwise.

C denotes a crystalline phase, S a smectic phase,  $S_C$  a smectic C phase,  $S_A$  a smectic A phase, N a nematic phase and I the isotropic phase.  $V_0$  denotes the capacitive threshold voltage.  $\Delta n$  denotes the optical anisotropy and  $n_0$  the ordinary refractive index (in each case at 589 nm).  $\Delta \epsilon$  denotes the dielectric anisotropy ( $\Delta \epsilon = \epsilon_{||} - \epsilon_{\perp}$ , where  $\epsilon_{||}$  denotes the dielectric constant parallel to the longitudinal molecular axes and  $\epsilon_{\perp}$  denotes the dielectric constant perpendicular thereto, in each case at 1 kHz). The electro-optical data were measured in a planar cell at 20°C, unless expressly stated otherwise. All physical properties are quoted and measured at 20°C, unless expressly stated otherwise. The cells are preferably brought in the "off" state.

Without further elaboration, it is believed that one skilled in the art can, using the preceding description, utilize the present invention to its fullest extent. The following preferred specific embodiments are,

therefore, to be construed as merely illustrative, and not limitative of the remainder of the disclosure in any way whatsoever.

5 The entire disclosures of all applications, patents and publications, cited above and of corresponding German Patent application No. 100 19 061.8, filed April 18, 2001, are hereby incorporated by reference.

10 The following examples are intended to illustrate the invention without limiting it. Above and below, percentages are percent by weight. All temperatures are given in degrees Celsius.  $\Delta n$  denotes the optical anisotropy (589 nm, 20°C),  $\Delta \epsilon$  denotes the dielectric anisotropy (1 kHz, 20°C), H.R. denotes the voltage holding ratio (at 100°C, after 5 minutes in an oven at 1 V), and  $V_0$ , the capacitive threshold voltage, was determined at 20°C and 1 kHz.

20 The calibrated rotational viscometer gave a rotational viscosity for ZLI-4792 (Merck KGaA) of 133 mPa · s at 20°C.

The storage stability was investigated in sealed test cells with an optical retardation of about 0.5  $\mu\text{m}$  using CU-1511 from DuPont, USA, as alignment layer. To this end, in each case 5 test cells were adhesively bonded on both sides to crossed polarizers and stored at fixed temperatures of 0°C, -10°C, -20°C, -30°C or -40°C. The cells were assessed visually for changes at intervals of 24 hours in each case. The storage time at the respective temperature  $t_{\text{store}}$  (T) was noted as the final time at which no change was observed in any of the cells.

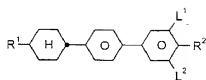
35

In the present application and in the following examples, the structures of the liquid-crystal compounds are specified by acronyms, which can be transformed into chemical formulae according to the

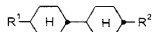
- following Tables A and B. All radicals  $C_nH_{2n+1}$  are straight-chain alkyl radicals having n or m carbon atoms. The coding according to Table B is self-evident. Table A specifies the acronym for the parent body only.
- 5 In individual cases, the acronym for the parent body is followed, separated therefrom by a hyphen, by a code for the substituents  $R^1$ ,  $R^2$ ,  $L^1$  and  $L^2$ :

Code for R <sup>1</sup> , R <sup>2</sup> , L <sup>1</sup> , L <sup>2</sup>	R <sup>1</sup>	R <sup>2</sup>	L <sup>1</sup>	L <sup>2</sup>
nm	C <sub>n</sub> H <sub>2n+1</sub>	C <sub>m</sub> H <sub>2m+1</sub>	H	H
nOm	C <sub>n</sub> H <sub>2n+1</sub>	OC <sub>m</sub> H <sub>2m+1</sub>	H	H
nO.m	OC <sub>n</sub> H <sub>2n+1</sub>	C <sub>m</sub> H <sub>2m+1</sub>	H	H
n	C <sub>n</sub> H <sub>2n+1</sub>	CN	H	H
nN.F	C <sub>n</sub> H <sub>2n+1</sub>	CN	F	H
nN.F.F	C <sub>n</sub> H <sub>2n+1</sub>	CN	F	F
nF	C <sub>n</sub> H <sub>2n+1</sub>	F	H	H
nOF	OC <sub>n</sub> H <sub>2n+1</sub>	F	H	H
nF.F	C <sub>n</sub> H <sub>2n+1</sub>	F	F	H
nF.F.F	C <sub>n</sub> H <sub>2n+1</sub>	F	F	F
nCl	C <sub>n</sub> H <sub>2n+1</sub>	Cl	H	H
nCl.F	C <sub>n</sub> H <sub>2n+1</sub>	Cl	F	H
nCl.F.F	C <sub>n</sub> H <sub>2n+1</sub>	Cl	F	F
nCF <sub>3</sub>	C <sub>n</sub> H <sub>2n+1</sub>	CF <sub>3</sub>	H	H
nOCF <sub>3</sub>	C <sub>n</sub> H <sub>2n+1</sub>	OCF <sub>3</sub>	H	H
nOCF <sub>3</sub>	C <sub>n</sub> H <sub>2n+1</sub>	OCF <sub>3</sub>	H	H
nOCF <sub>2</sub>	C <sub>n</sub> H <sub>2n+1</sub>	OCHF <sub>2</sub>	H	H
nS	C <sub>n</sub> H <sub>2n+1</sub>	NCS	H	H
rVsN	C <sub>r</sub> H <sub>2r+1</sub> -CH=CH-C <sub>s</sub> H <sub>2s</sub> -	CN	H	H
rEsN	C <sub>r</sub> H <sub>2r+1</sub> -O-C <sub>2</sub> H <sub>2s</sub> -	CN	H	H
nAm	C <sub>n</sub> H <sub>2n+1</sub>	C≡C-C <sub>m</sub> H <sub>2m+1</sub>	H	H
nCF <sub>3</sub> .F.F	C <sub>n</sub> H <sub>2n+1</sub>	CF <sub>3</sub>	F	F
nOCF <sub>3</sub> .F	C <sub>n</sub> H <sub>2n+1</sub>	OCF <sub>3</sub>	F	H
nOCF <sub>3</sub> .F.F	C <sub>n</sub> H <sub>2n+1</sub>	OCF <sub>3</sub>	F	F
nOCF <sub>2</sub> .F.F	C <sub>n</sub> H <sub>2n+1</sub>	OCHF <sub>2</sub>	F	F

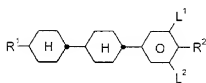
**Table A:**



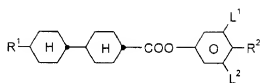
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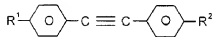
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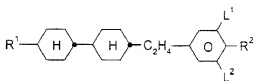
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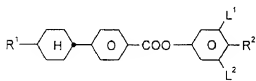
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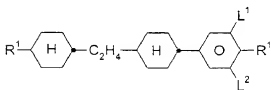
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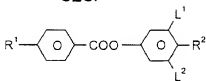
**ECCP**



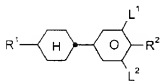
**HP**



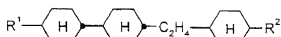
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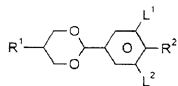
**ME**



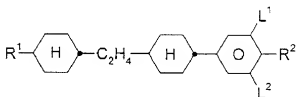
**PCH**



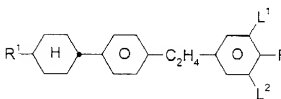
**CH**



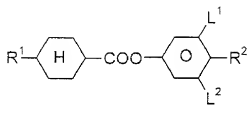
**PDX**



**BECH**

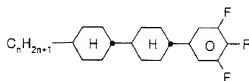


**EBCH**

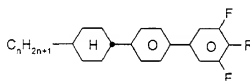


**D**

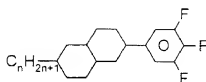
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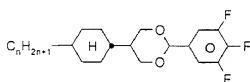
**CCP-nF.F.F**



**BCH-nF.F.F**

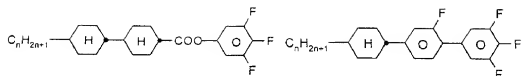


**DHP-nF.F.F**



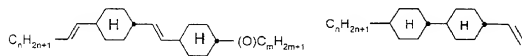
**CDU-nF**





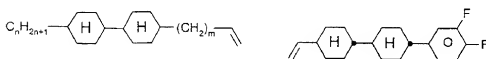
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**CGU-n-F**



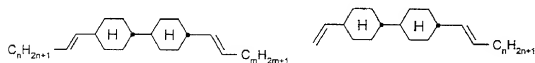
**CVCP-nV-(O)m**

**CC-n-V**



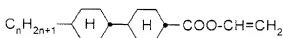
**CC-n-mV**

**CCG-V-F**

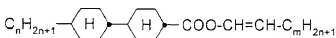


**CC-nV-Vm**

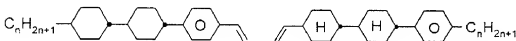
**CC-V-Vn**



**CC-n-ZV**

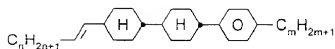


**CC-n-ZVm**

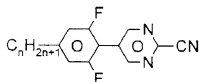


**CCP-n-V**

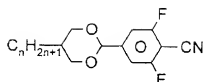
**CCP-V-n**



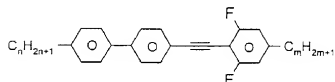
**CCP-nV-m**



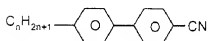
**UM-n-N**



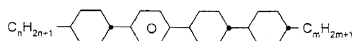
**DU-n-N**



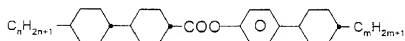
**PPTUI-n-m**



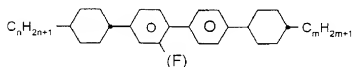
**K3 · n**



**CPCC-nm**



**CCPC-nm**



**CBC-nm(F)**

Preferred displays contain media comprising, in particular, one or more compounds from Tables A and B in addition to the compounds of the formula I.

Particularly preferred IPS displays contain media comprising

- one or more compounds of one of the formulae in Table A and one or more compounds of the formulae in Table B
- one or more compounds of each of two or more different types of compounds of the formulae in Table A
- one or more compounds of each of two or more different types of compounds of the formulae in Table B
- one or more compounds of each of four or more compounds from the group consisting of the compounds of the formulae in Tables A and B.

The examples below are intended to illustrate the invention without restricting its scope in any way. However, the examples show typical mixture concepts and the physical parameters and parameter combinations achievable therewith.

# Example 1

An IPS display contains a nematic mixture having

Compound Abbreviation	Conc./%	Physical properties
GZU-3-N	7.0	$T(N,I) = 72.0^{\circ}\text{C}$
PCH-3	6.0	$T(S,N) < -20^{\circ}\text{C}$
PDX-3	7.0	$n_e (589 \text{ nm}, 20^{\circ}\text{C}) = 1.5743$
CCZU-2-F	7.0	$\Delta n (589 \text{ nm}, 20^{\circ}\text{C}) = 0.0912$
CCZU-3-F	15.0	$\epsilon_{\perp} (1 \text{ kHz}, 20^{\circ}\text{C}) = 4.6$
CCZU-5-F	7.0	$\Delta\epsilon (1 \text{ kHz}, 20^{\circ}\text{C}) = 10.5$
CCP-V-1	12.0	$k_1 (20^{\circ}\text{C}) = 14.7 \text{ pN}$
BCH-32	5.0	$k_3/k_1 (20^{\circ}\text{C}) = 1.48$
CC-5-V	20.0	$\gamma_1 (20^{\circ}\text{C}) = 95 \text{ mPa}\cdot\text{s}$
PCH-302	<u>14.0</u>	
$\Sigma$	100.0	$V_0 (1 \text{ kHz}, 20^{\circ}\text{C}) = 1.03 \text{ V}$

5

and has good contrast.

Example 2

An IPS display contains a nematic mixture having

Compound Abbreviation	Conc./%	Physical properties
UZU-3-N	7.0	$T(N,I) = 72.0^{\circ}\text{C}$
PCH-3	6.0	$T(S,N) < -20^{\circ}\text{C}$
PDX-3	7.0	$n_e (589 \text{ nm}, 20^{\circ}\text{C}) = 1.5746$
CCZU-2-F	7.0	$\Delta n (589 \text{ nm}, 20^{\circ}\text{C}) = 0.0901$
CCZU-3-F	15.0	$\epsilon_{\perp} (1 \text{ kHz}, 20^{\circ}\text{C}) = 4.8$
CCZU-5-F	7.0	$\Delta\epsilon (1 \text{ kHz}, 20^{\circ}\text{C}) = 11.0$
CCP-V-1	13.0	$k_1 (20^{\circ}\text{C}) = 15.1 \text{ pN}$
BCH-32	7.0	$k_3/k_1 (20^{\circ}\text{C}) = 1.53$
CC-5-V	20.0	$\gamma_1 (20^{\circ}\text{C}) = 91 \text{ mPa}\cdot\text{s}$
PCH-302	<u>11.0</u>	
$\Sigma$	100.0	$V_0 (1 \text{ kHz}, 20^{\circ}\text{C}) = 1.00 \text{ V}$

5

and has good contrast.

# Comparative Example

An IPS display contains a nematic mixture having

Compound Abbreviation	Conc./%	Physical properties
ME2N.F	3.0	$T(N,I) = 73.5^{\circ}\text{C}$
ME3N.F	6.0	$T(S,N) < -20^{\circ}\text{C}$
PCH-3	5.0	$n_e (589 \text{ nm}, 20^{\circ}\text{C}) = 1.5756$
PDX-3	7.0	$\Delta n (589 \text{ nm}, 20^{\circ}\text{C}) = 0.0906$
CCZU-2-F	7.0	$\epsilon_1 (1 \text{ kHz}, 20^{\circ}\text{C}) = 4.6$
CCZU-3-F	15.0	$\Delta\epsilon (1 \text{ kHz}, 20^{\circ}\text{C}) = 11.0$
CCZU-5-F	7.0	$k_1 (20^{\circ}\text{C}) = 10.3 \text{ pN}$
CCP-V-1	16.0	$k_3/k_1 (20^{\circ}\text{C}) = 1.52$
BCH-32	2.0	$\gamma_1 (20^{\circ}\text{C}) = 96 \text{ mPa}\cdot\text{s}$
CC-5-V	20.0	
PCH-302	<u>12.0</u>	$V_0 (1 \text{ kHz}, 20^{\circ}\text{C}) = 1.06 \text{ V}$
$\Sigma$	100.0	

5

and has at best adequate contrast.

10 Directly compared to the liquid-crystal mixtures of Examples 1 and 2, which were adjusted to virtually the same application parameters, in particular clearing point and optical anisotropy, the Comparative Example has both a higher threshold and a higher rotational viscosity.

15

The preceding examples can be repeated with similar success by substituting the generically or specifically described reactants and/or operating conditions of this invention for those used in the preceding examples.

20

25 From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention and, without departing from the spirit and scope thereof, can make various changes and

modifications of the invention to adapt it to various usages and conditions.